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Drag forces of natural trees of different size: experiments in a towing tank

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Reliable estimation of hydraulic resistance is of great importance in practical applications such as river and wetland restoration as well as flood prediction and management. Parameters describing riparian vegetation need to be physically sound and readily measurable. For these purposes, several researchers have studied the hydraulic resistance in flumes with living and artificial plants both in arrays and with isolated plants. However, due to the restrictions of flume size the experiments are often conducted with parts of trees, twigs or branches. Consequently, it is not clear how the size (parts of trees or small trees vs. full scale trees) affects the hydraulic resistance.

We conducted direct drag force measurements for 23 tree individuals of different heights (0.9 m – 3.5 m) in a towing tank. The investigated species were Common Alder (Alnus glutinosa), Goat Willow (Salix caprea), Silver Birch (Betula pendula) and White Birch (Betula pubescens). The forces were measured at velocity ranges of 0.1-2.5 m/s and 0.1-2.0 m/s both in leafy and leafless conditions, respectively. The measurement system consisted of three load cells measuring the main flow direction. Two different load cell setups were used depending on the size of the specimen to allow for accurate force measurement. For the smaller trees the load cells were replaced with more sensitive sensors, and the resulting ranges of the load cells were from 1 to 1000 N and from 0.1 to 100 N. Frontal and side projected areas and bending of the specimens were recorded during the measurements using submerged video cameras. For all specimens, wet and dry biomass, projected area in still air, and one-sided leaf area were determined. In order to construct a 3D-model of the trees, the specimens were laser scanned from three directions with a terrestrial laser scanner (TLS). The resulting point cloud had a millimeter resolution, and provided detailed information about the plant characteristics, such as leaf area, projected area, and stem volume with the corresponding vertical distributions.

The experiments provided information for improving understanding about the impact of tree size on drag (different plant properties such as flexibility and deformation), contribution of foliage to drag, and characterization of vegetation (laser scanning vs. biomass and photographs). The results showed that the contribution of leaves to the total drag decreased from 80% at the lowest velocity (0.1 m/s) to around 40% for velocities above 0.5 m/s. For the smaller trees, height 90-150 cm, the contribution of leaves to the total drag was 50% at the velocity of 0.5 m/s and higher. These differences may be attributed to the different tree morphology of the smaller trees compared to the taller trees. The differences in the flexibility and plant characteristics will be elaborated in the further analyses of the data.